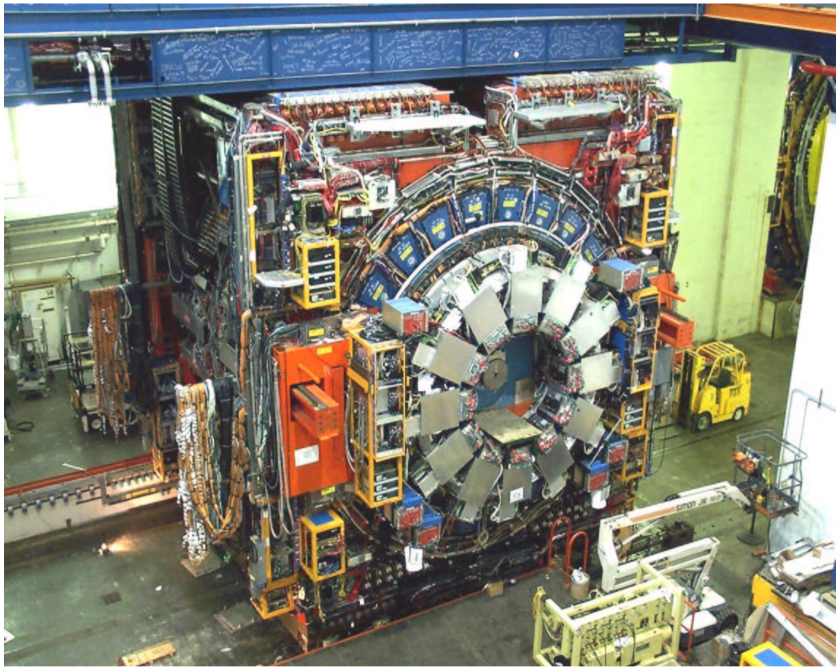
Search for $B_s \to \mu^+\mu^-$ and $B_d \to \mu^+\mu^-$ Decays at CDF

Cheng-Ju Lin
(Fermilab)

Representing CDF Collaboration



SUSY 2004
Tsukuba, Japan

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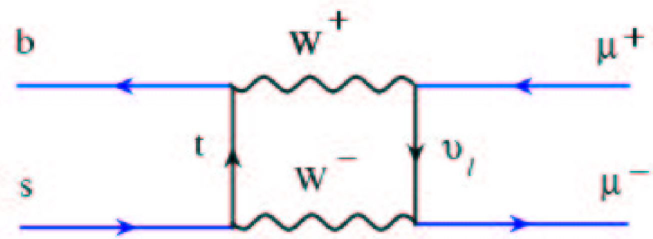
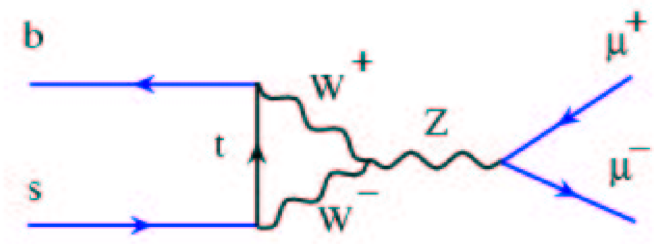
INTRODUCTION

- In the Standard Model, the decay of B $\rightarrow \mu^+\mu^-$ is heavily suppressed





$$BR(B_s \rightarrow \mu^+\mu^-) = (3.5 \pm 0.9) \times 10^{-9}$$

(Buchalla & Buras, Misiak & Urban)

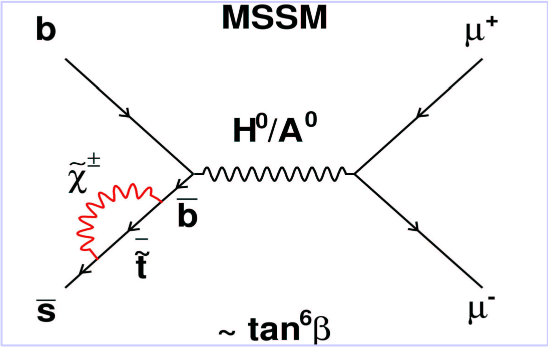
- Experimentally, only upper limit on the branching ratio exist. Previous best published limit:

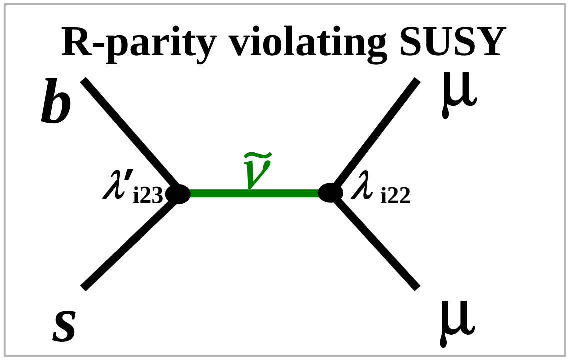
$$BR(B_s \rightarrow \mu^+\mu^-) < 2.0 \times 10^{-6} @ 90\% CL$$

(CDF, PRD 57 (1998) 3811R)

INTRODUCTION

- In many extensions of the Standard Model, the BR is enhanced by many orders of magnitude





- MSSM: Br($B\rightarrow\mu\mu$) is proportional to $\tan^6\beta$
  BR could be as large as ~100 times the SM prediction

- Tree level diagram is allowed in R-parity violating SUSY models
  Also naturally accommodate large enhancement

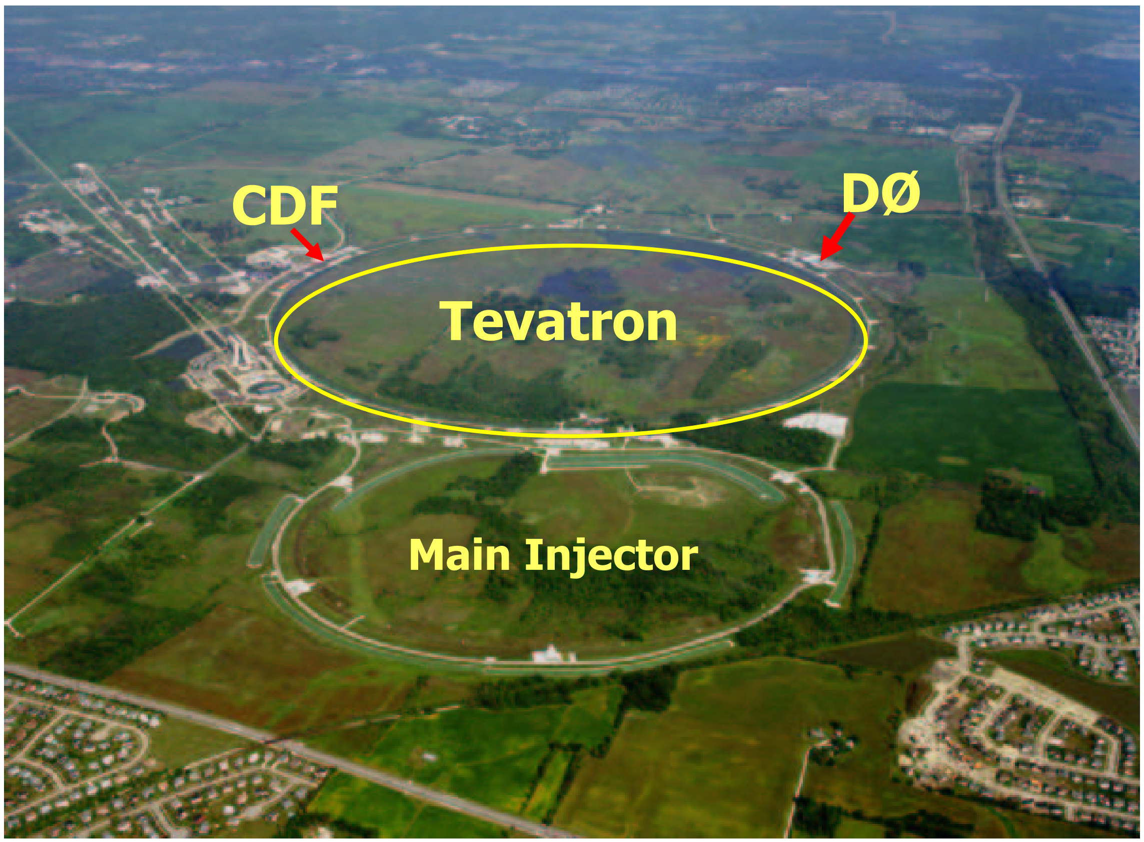
INTRODUCTION

- With the current dataset, we expect 0 event based on Standard Model prediction.
- If we observe the decay → **NEW PHYSICS!!!**
- No observation → exclude SUSY parameter space
- Could the universe be:

or

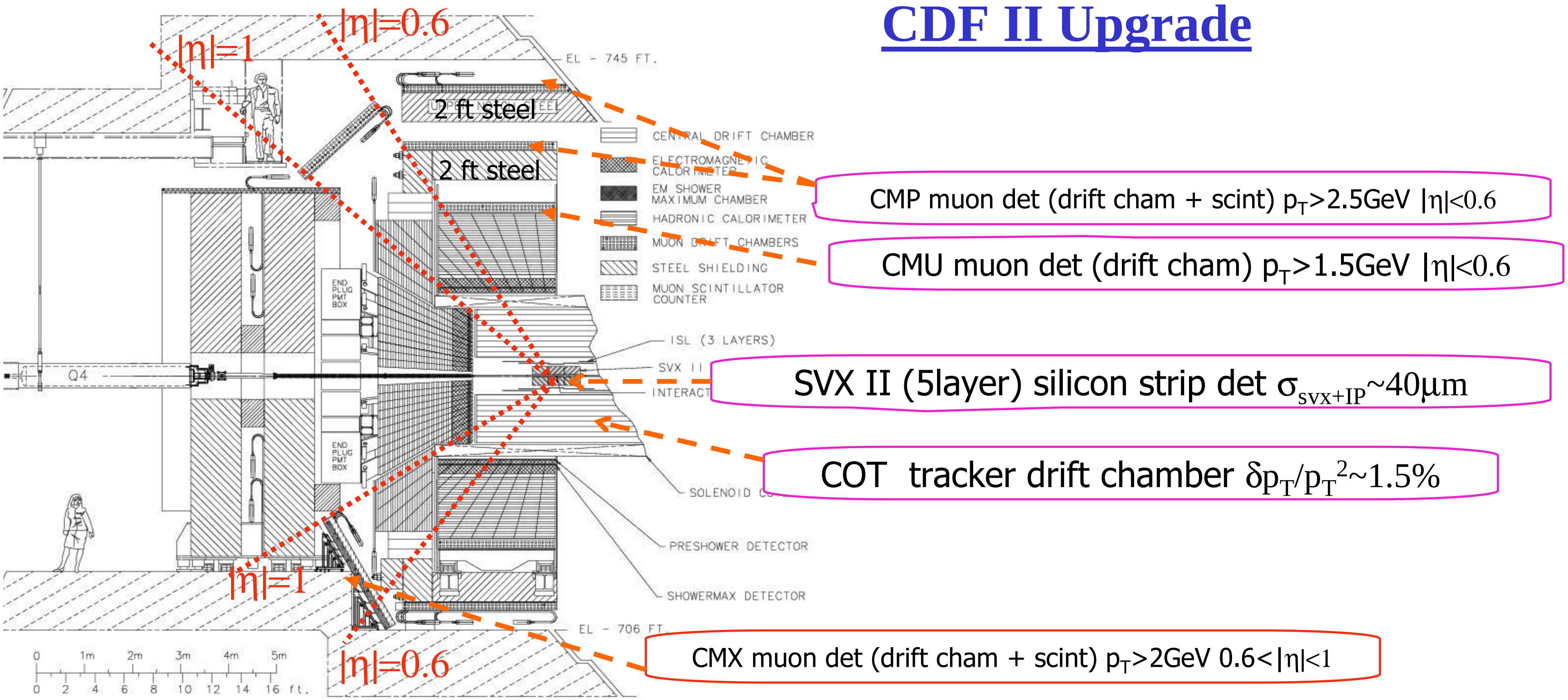
TEVATRON

- Tevatron is the highest energy collider in the world
  $E_{cm}(p\bar{p}) = 1.96$ TeV
- RunII physics run began in Mar 2001 (~400/pb delivered so far)
  Current peak luminosity 7.8 E31/cm^2 sec (accelerator routinely breaks record luminosity)



- B production cross-sec is ~30μb at Tevatron (1nb at PEPII)
- All B species are produced ($B^+ : B_d : B_s : \Lambda_b$,)
- This analysis uses 171/pb of data

CDF II Upgrade



Highlights:

- Silicon detector coverage is a factor of 2 larger
- Detector electronics upgraded to handle 396ns bunch crossing
- Track triggered threshold is lowered ⟶ higher efficiency

INGREDIENTS OF THE ANALYSIS

For the search:

- Using 171/pb of data from the di-muon trigger sample
- Reconstructing di-muon events in the B mass window
- Measuring the branching ratio, or if no events observed $\longrightarrow$ setting a limit

$$\langle BR(B_s \to \mu\mu) \rangle = \frac{(N_{candidates} - Bgd)}{\alpha \cdot \varepsilon_{total} \cdot \sigma_{Bs} \cdot \int L dt}$$

For the analysis, we need to:

- have a good understanding of the background,
- accurately measure the acceptance and efficiencies

Analysis optimization:

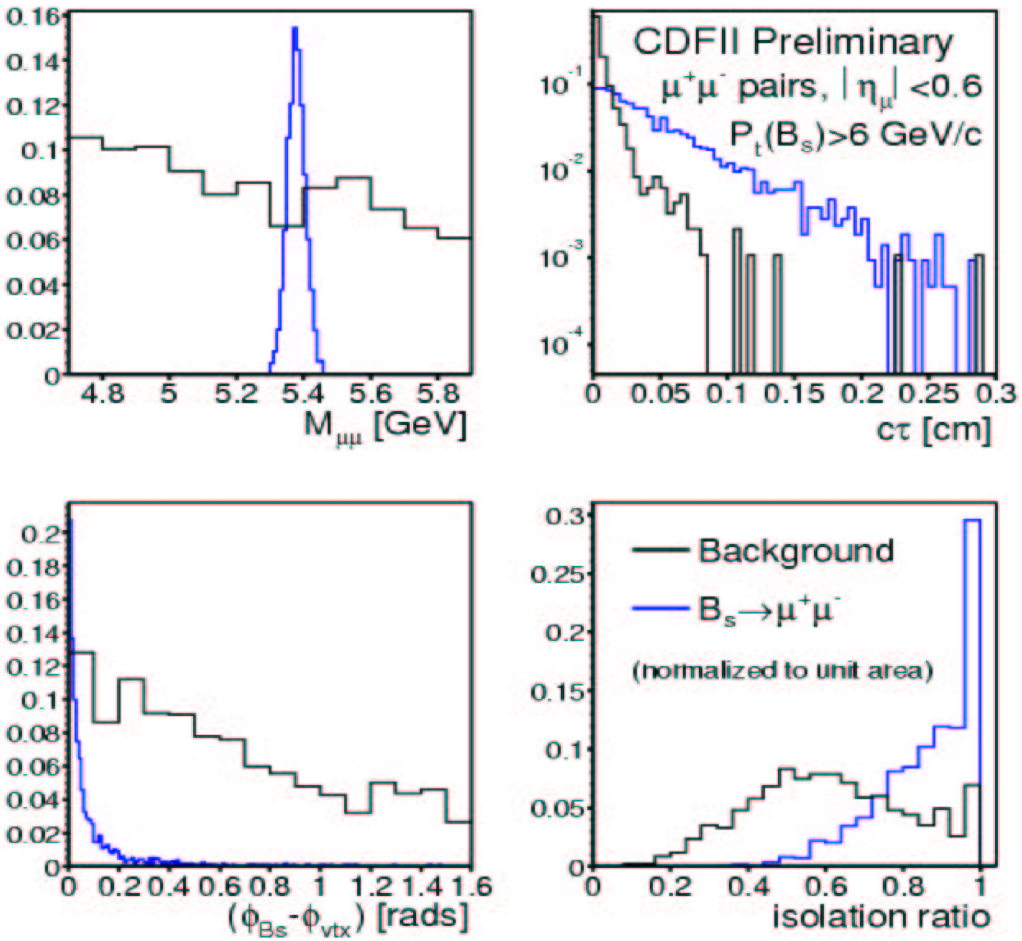
Figure of merit $\longrightarrow$ expected 90% C.L. upper limit of the branching ratio

To avoid bias:

Analysis was performed blind $\longrightarrow$ didn't look in the signal region
for analysis optimization.

ANALYSIS SELECTION

We use 4 discriminating variables to reject the enormous backgrounds



Discriminating Variables:

- Invariant mass (ΔM)
- Proper (2d) decay time:
  $c\tau$ = Lxy*M/Pt_B
- B flight and vertex axis opening angle:
  $\Delta\Phi = \phi(B) - \phi(vtx)$
- Isolation variable:
  Iso= Pt_B/(Σ_trk + Pt_B)

BACKGROUND SOURCES

$B \longrightarrow \pi\pi$, $K\pi$, KK (with K, π misidentified as muons):

- Generated a sample MC two-body hadronic B decays
- Take muon fake rates for pion and kaon from data
- Convolute muon fake rates with pT spectra

$\longrightarrow$ Background contribution from two body hadronic B decay is more than 100 times smaller than expected limit.

Other resonance feed-downs (surprises):

- Generated a sample of generic B-Bbar decays (equivalent to ~190pb^{-1})
- Apply analysis cuts on the sample

$\longrightarrow$ No events survived all cuts

Combinatoric background (μ+fake, fake+fake, $b\longrightarrow\mu$ + $c\longrightarrow\mu$, etc…) :

Estimated from upper and lower mass side-bands

BACKGROUND ESTIMATE

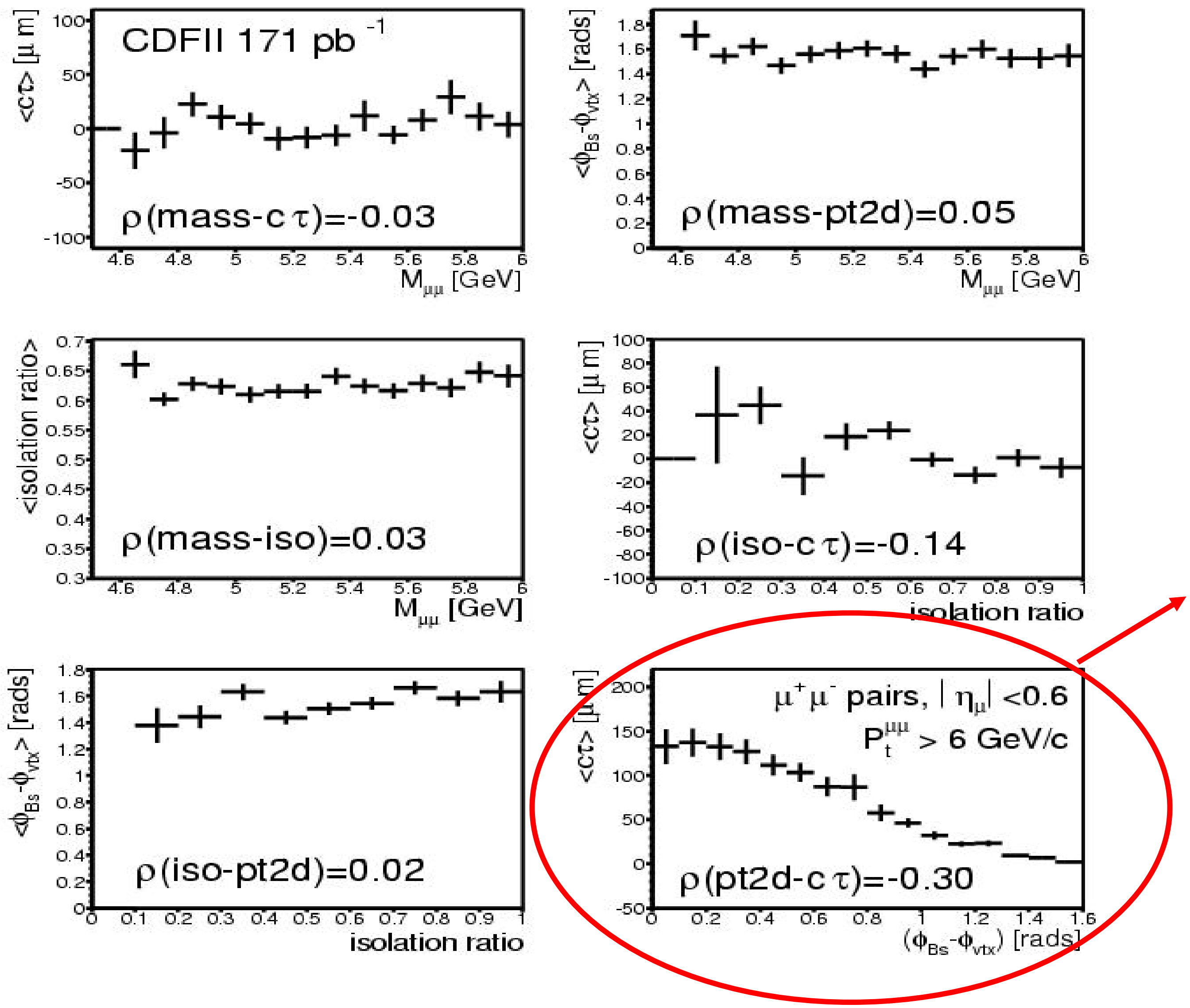
To improve the uncertainty on background estimate, we factorize the rejection for each independent set of cuts:

$N(bgd) = N(sideband|c\tau,\Delta\Phi)*R(iso)*R(\Delta M)$

- $N(sideband|c\tau,\Delta\Phi)$ == no. of events in sideband region passing $c\tau$ and $\Delta\Phi$ cuts
- R(iso) == fraction of background expected to survive a given isolation cut
- $R(\Delta M)$ == given N(sideband), estimate of N(signal window)

Correlation Profile Plots

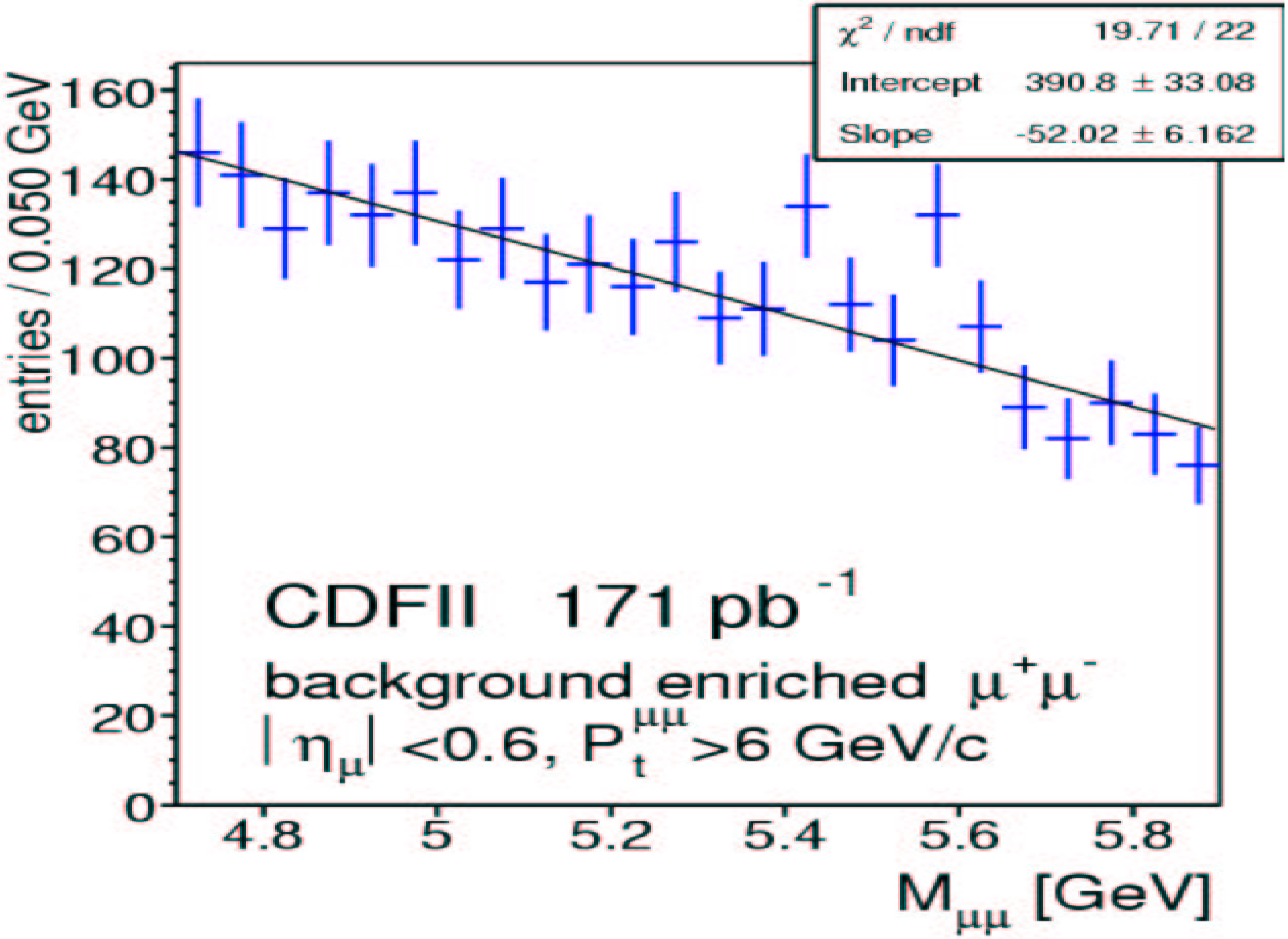
$$\rho_{xy} = \frac{1}{N-1} \cdot \frac{\sum_{i=1}^{N} (x_i - \hat{x})(y_i - \hat{y})}{\sigma_x \sigma_y}$$



cτ and ΔΦ are strongly correlated.

Background Invariant Mass Distribution (Data)

For background estimate, we assume the background shape is linear!



Cross-Check of Background Estimate Procedure

Control Samples from data:

(1) **SS -** $\longrightarrow$ same sign ($\mu^{\pm}\mu^{\pm}$) $c\tau<0$ events,

(2) **SS +** $\longrightarrow$ same sign ($\mu^{\pm}\mu^{\pm}$) $c\tau>0$ events,

(3) **OS -** $\longrightarrow$ opposite sign ($\mu^{+}\mu^{-}$) $c\tau<0$ events,

For each sample above, we repeated the cross-checks using three different set of cuts:

Cut A : $c\tau>100\mu m$, $\Delta\Phi < 0.20$rad, Iso>0.6 (loose cuts)

Cut B : $c\tau>150\mu m$, $\Delta\Phi < 0.20$rad, Iso>0.7 (near optimal)

Cut C : $c\tau>200\mu m$, $\Delta\Phi < 0.10$rad, Iso>0.8 (hard cuts)

Checking Background Estimate Procedure

	Sample	N(expctd)	N(obsrvd)	P(>=obs|exp)
A	OS-	10.43 +/- 1.89	16	4%
	SS+	5.80 +/- 0.98	4	83%
	SS-	6.72 +/- 1.10	7	51%
	Sum	22.94 +/- 3.14	27	
B	OS-	3.69 +/- 0.80	6	17%
	SS+	1.83 +/- 0.35	1	84%
	SS-	2.32 +/- 0.42	4	20%
	Sum	7.84 +/- 1.19	11	
C	OS-	0.64 +/- 0.22	1	47%
	SS+	0.29 +/- 0.08	0	75%
	SS-	0.27 +/- 0.08	1	24%
	Sum	1.21 +/- 0.27	2	

ACCEPTANCE AND EFFICIENCY

$$\alpha \cdot \varepsilon_{total} = \alpha \cdot \varepsilon_{trig} \cdot \varepsilon_{reco} \cdot \varepsilon_{final}$$

- α (geometric acceptance for pT($B_{s,d}$)>6GeV, $|\eta|<0.6$):
  Estimated from full Monte Carlo simulation $\longrightarrow$ (6.6±0.5)%

- ε_{trig} (di-muon trigger efficiency):
  Measured directly from the data using a sample of $J/\Psi \longrightarrow \mu\mu$ decays
  $\longrightarrow$ (85±3)%

- ε_{reco} (tracking, silicon, muon and vertex reconstruction):
  Absolute tracking efficiency is obtained by embedding MC muon tracks in data. The rest are measured from data using $J/\Psi \longrightarrow \mu\mu$ decays.
  $\longrightarrow$ (67±3)%

- ε_{final} (efficiency of analysis selection cuts: ΔM, $c\tau$,$\Delta\Phi$, Isol):
  - Estimated from Monte Carlo (varied between 28-78% based on ~200 different combination of selection cuts)
  - Only these 4 parameters are allowed to vary in the analysis optimization
  - Cross-checked using $B^+ \longrightarrow J/\Psi K^+$ data and MC $\longrightarrow$ assigned ±5% syst

OPTIMIZATION RESULTS

Optimization:

Poisson prob

$$\left\langle BR(B_s \to \mu\mu) \right\rangle_{CL}^{90\%} = \frac{\sum_n N_{CL}^{90\%}(n \mid n_{bg}) \cdot P(n \mid n_{bg})}{2 \cdot \alpha \cdot \varepsilon_{total} \cdot \sigma_{Bs} \cdot \int L dt}$$

The optimal set of final selection criteria is:

$\Delta M_{\mu\mu}$ = +/- 80 MeV around $M(B_s)$=5.369 GeV

$c\tau$ > 200 μm

$\Delta\Phi$ < 0.10 rad

Isolation > 0.65

which corresponds to:

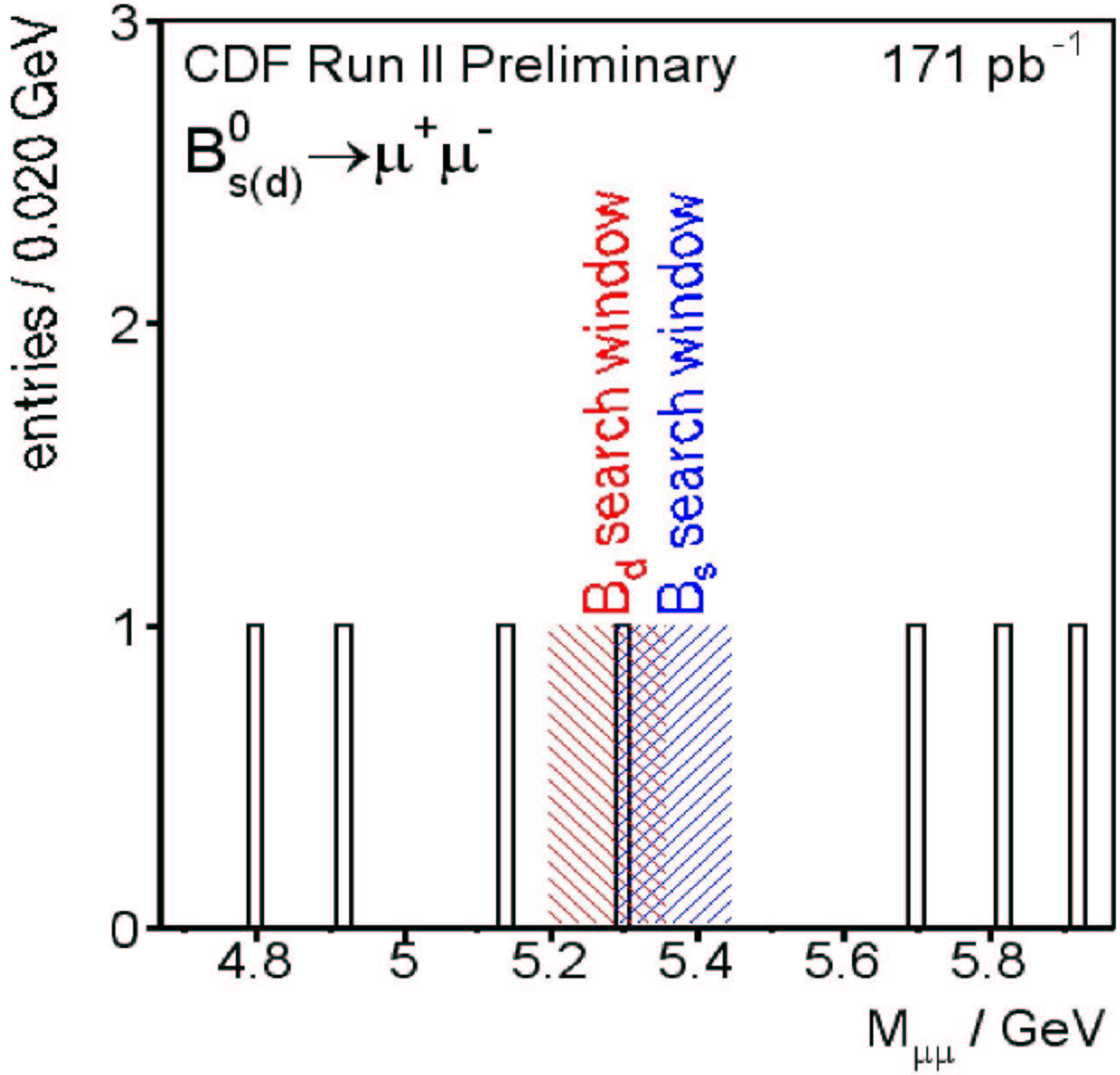
$\alpha * \varepsilon_{total}$ = (2.0 +/- 0.2)%

single event sensitivity = 1.6 x 10^{-7}

<Bgd> in 171 pb^{-1} = 1.1 +/- 0.3 events

($\alpha\varepsilon$ & Bgd are unchanged for mass window centered on 5.279 GeV for the Bd $\to \mu^+\mu^-$ search)

B → μμ RESULTS



We have one common event within the Bs and Bd 3σ mass window.

The expected bkg is 1.05 ±0.30 (for Bs) and 1.07 ±0.31 (for Bd).

$B \rightarrow \mu\mu$ RESULTS

For optimized cuts of ($c\tau$, $\Delta\phi$, iso) = (>200 μm, <0.10 rads,Iso >0.65) and a $\pm$ 80 MeV window around world avg Bs,d mass:

Bs: $\alpha \times \varepsilon = 2.03 \pm 0.21\%$

<bgd> = 1.05 ± 0.30 events in 171 pb^{-1}

We observed 1 event which yields a limit of:

5.8E-7 @ 90% CL

7.5E-7 @ 95% CL

Previous best published limit = 2.6E-6 @ 95% CL (CDF Run I)

Bd: $\alpha \times \varepsilon = 1.99 \pm 0.21\%$

<bgd> = 1.07 ± 0.31 events in 171 pb^{-1}

We observed 1 event which yields a limit of:

1.5E-7 @ 90% CL

1.9E-7 @ 95% CL

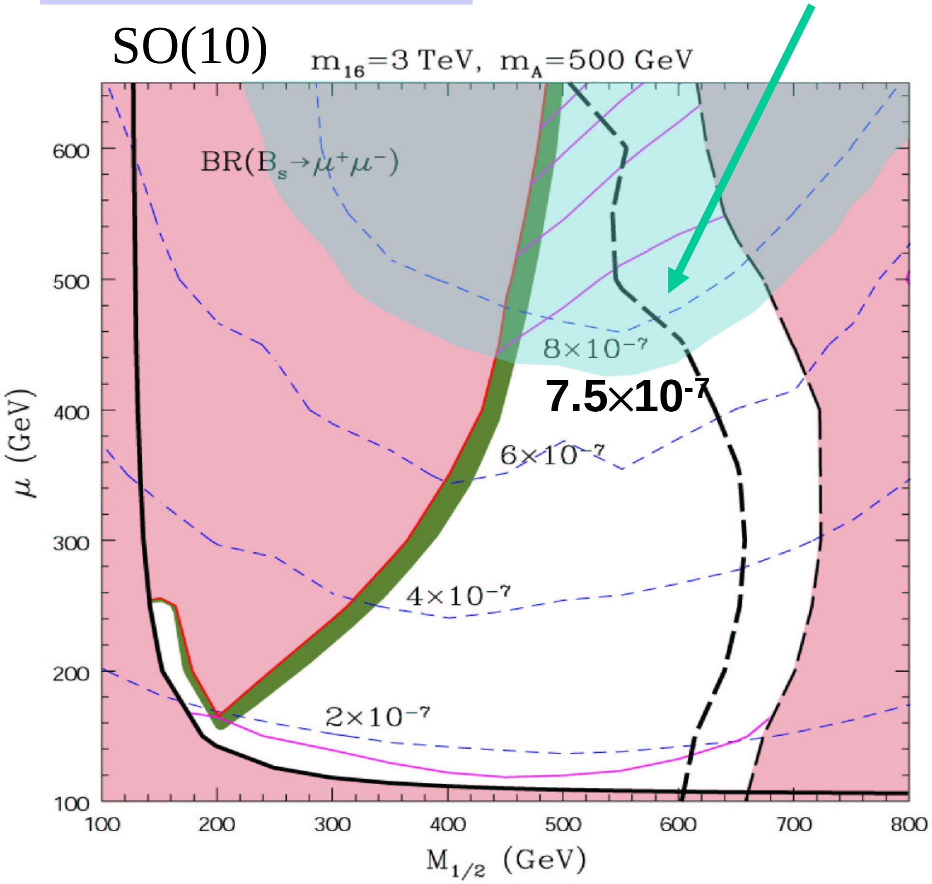
Current best published limit = 1.6E-7 @ 90% CL (Belle)

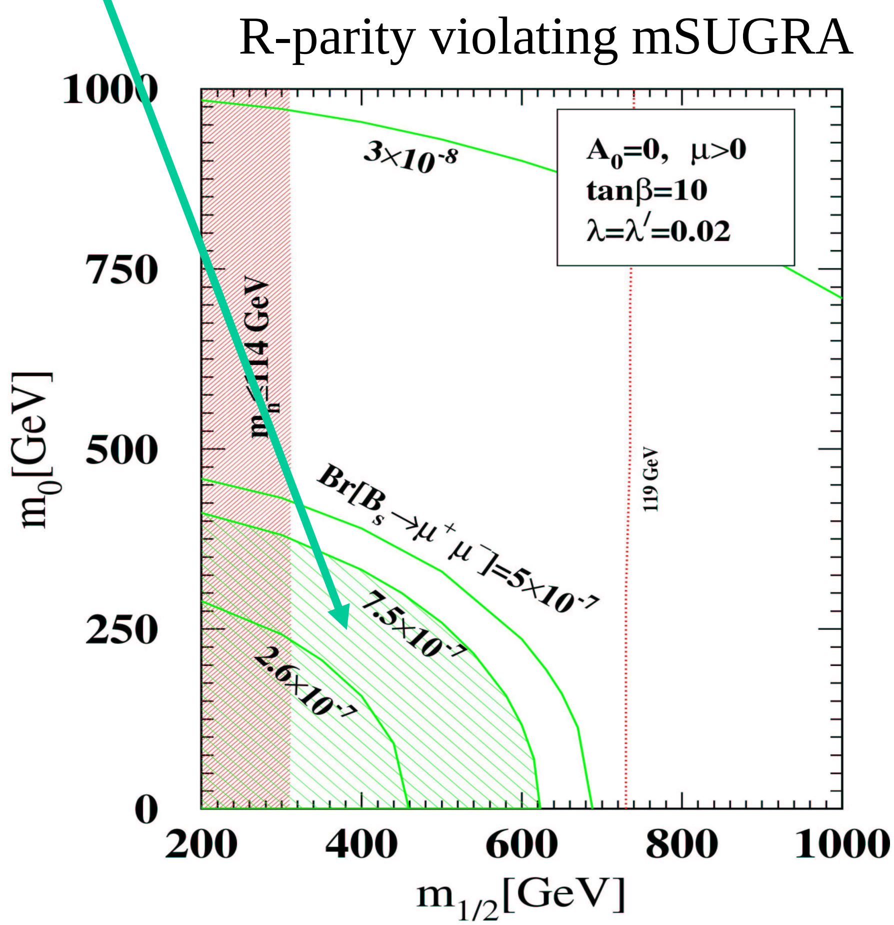
Some Excluded SUSY Regions From This Result

R. Dermisek *et al.*, hep-ph/0304101

Newly excluded regions

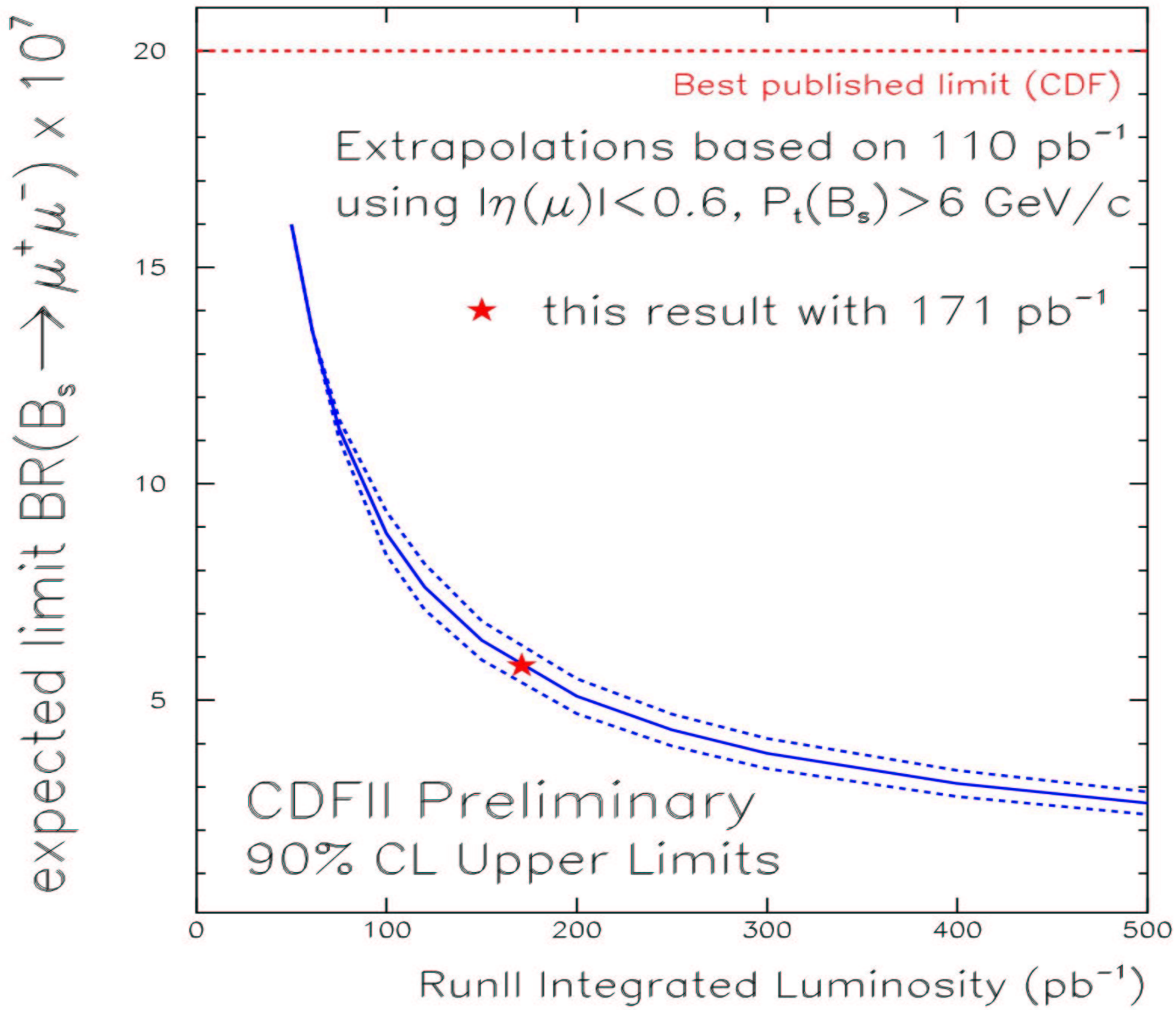
R. Arnowitt *et al.*, PLB 538 (2002) 121, new plot by B.Dutta





This new result excludes a significant portion of SUSY phase-space !!!

Expected Limit on Br(Bs → μμ) vs. Luminosity



- Current set of cuts are optimized for ~400 pb^{-1}
- Will need to re-optimize when we have more than 400 pb^{-1} of data to push limit < 10^{-8}

SUMMARY AND PLANS

- We have updated the analysis using 171pb^{-1} of data.

- The upper limits on the branching ratio are:

Br(Bs $\rightarrow$ μμ) < 5.8E-7 @ 90% CL

Br(Bs $\rightarrow$ μμ) < 7.5E-7 @ 95% CL

Br(Bd $\rightarrow$ μμ) < 1.5E-7 @ 90% CL

Br(Bd $\rightarrow$ μμ) < 1.9E-7 @ 95% CL

- **Bs result is a factor of 3 better than the previous published limit**
  Bd result is slightly better than the Belle published limit

- Paper has recently been submitted and accepted by PRL

- We are in the process of updating the analysis using full data sample and improved analysis method. Will release the new result soon.